Running head: COST IDENTIFICATION AND BENEFITS

Cost Identification and Benefits of the Picture Archiving and Communication System at Walter Reed Army Medical Center

Hunter R. Clouse

Baylor University

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 17 April 1998	3. REPORT TYPE AND DATES COVERED FINAL REPORT (07-9 TO 07-98)

4. TITLE AND SUBTITLE
COST IDENTIFICATION AND BENEFITS OF THE PICTURE ARCHIVING AND COMMUNICATION SYSTEM AT WALTER REED ARMY MEDICAL CENTER

5. FUNDING NUMBERS

6. AUTHOR(S)
COL HUNTER R. CLOUSE, DC

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
WALTER REED ARMY MEDICAL CENTER
WASHINGTON, DC 20307

8. PERFORMING ORGANIZATION REPORT NUMBER
9-98

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US ARMY MEDICAL DEPARTMENT CENTER AND SCHOOL
BLDG 2841 MCCS-HRA US ARMY-BAYLOR PROGRAM IN HCA
3151 SCOTT RD SUITE 1412
FORT SAM HOUSTON, TEXAS 78234-6135

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A proposed plan for complete implementation of the Picture Archiving and Communication System (PACS) at Walter Reed Army Medical Center (WRAMC) was assessed by cost identification and provider satisfaction. The annual oprating cost for year 1 amounts to $2,485,924.80 and ranges from $2,774,724.80 to $1,812,861.80 for years 2 throught 8. In contrast, the annual cost of film-based radiology is $913,665.97. Stepwise multiple regression analysis revealed that the most significant factors associated with overall satisfaction are (1) "user friendliness," (2) the effect on efficiency of clinical practice, (3) reliability, and (4) confidence in diagnosis using the PACS, which resulted in a shared variance of .557 with $F(4,114)=35.847$, $p<.0001$. Recommendations are presented for expansion of the PACS at WRAMC. The PACS offers distinct advantages when compared to conventional film-based radiology. However, hardware, software, information system, and maintenance costs of the PACS are high. Clinicians and hospital administrators must determine if PACS is the best method, consistent with their budget, to solve problems with storage and distribution of medical image information.

14. SUBJECT TERMS
PICTURE ARCHIVING AND COMMUNICATION SYSTEM

15. NUMBER OF PAGES
71

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
N/A	N/A	N/A	UL

Acknowledgments

The author would like to acknowledge and thank LTC Michael Brazaitis, Chief, Department of Radiology, Walter Reed Army Medical Center and his staff for their assistance in retrieving data for the cost identification analysis. The author would also like to express his sincere appreciation to LTC Janet Harris, Chief, Nursing Education and Research Service, Walter Reed Army Medical Center for her guidance in the statistical analysis of the survey results and critical review of the manuscript.

Abstract

A proposed plan for complete implementation of the Picture Archiving and Communication System (PACS) at Walter Reed Army Medical Center (WRAMC) was assessed by (1) cost identification analysis and (2) provider satisfaction (employing an 11-item survey instrument). The annual operating cost for year 1 amounts to $2,485,924.80 and ranges from $2,774,724.80 to $1,812,861.80 for years 2 through 8. In contrast, the annual cost of film-based radiology is $913,665.97. Survey participants (n=119) agreed highly that PACS provides rapid access to radiographic images and that the presence of multiple viewing stations is important in their clinical practice. Furthermore, they are confident in their diagnoses using digital images and they agree that the PACS improves the quality of care delivered. Overall satisfaction with the current PACS was moderate ($\underline{M} = 2.17 \pm .87$) based on a five-point Lickert scale where 1.00 equaled complete satisfaction. Satisfaction varied by department and type of provider. Stepwise multiple regression analysis revealed that the most significant factors associated with overall satisfaction are (1) "user friendliness," (2) the effect on efficiency of clinical practice, (3) reliability, and (4) confidence in diagnosis using PACS, which resulted in a shared variance, $\underline{R}^2 = .557$ with $\underline{F}\ (4, 114) = 35.847$, $\underline{p} < .0001$. Recommendations are presented for expansion of PACS at WRAMC. PACS offers distinct advantages when compared to conventional film-based radiology. However, hardware, software, information system, and maintenance costs of a PACS are high. Clinicians and hospital administrators must determine if a PACS is the best method, consistent with their budget, to solve problems with storage and distribution of medical image information.

Table of Contents

List of Tables

Table

List of Figures

Figure

Introduction

Telemedicine has many definitions, but may be described as a combination of telecommunications technology and medical expertise designed to enhance the delivery of medical care or medical education (Goldberg, 1996). Use of communication systems to disseminate medical expertise is not new. An article describing the examination of a child at home using interactive videoconferencing appeared in the magazine *Radio News* in April 1924, three years before the invention of the television. However, first generation telemedicine systems were not deployed until the 1960s and 1970s.

Today there is renewed interest in telemedicine, which may be attributed to (1) rapid advances in telecommunication and information management technologies that are applicable to the delivery of medical services and (2) increased demand for equal access to high quality medical care at a reasonable cost (Goldberg, 1996).

Teleradiology, the most mature of telemedicine "subspecialties," has benefited from more than twenty years of research on the application of digital technology to the display and management of radiographic images, with particular emphasis on transmission of those images both within and between medical treatment facilities (Goldberg, 1996). Teleradiology systems have several applications. This technology may be used for the purpose of primary readings (without review of original radiographs). These systems may also be used for consultation or second opinions in difficult cases or to supplement coverage after normal working hours or during planned or unexpected absences in a radiology practice.

During the past two decades, radiology departments have experienced a progressive shift from capturing an image on a photographic plate to capturing it with radiation detectors whose output signals can be digitized (Hynes, Stevenson & Nahmias, 1997). Digital radiology has

distinct advantages. All data are preserved, transported, sorted, read, stored, and retrieved electronically and expeditiously. Additionally, image modification is possible. Whereas images on conventional films are fixed (the only modification possible is to use a brighter light), the contrast of digital images may be altered to improve viewing quality. In contrast to digital images, conventional radiographic film is expensive, can be used in just one location at a time, requires a great deal of storage space, may be over- or under-exposed, and often can be lost or misplaced (Hynes et al., 1997).

The term "Picture Archiving and Communication System" (PACS), also known as image management and communication system (Tucker, Barnes & Koehler, 1995a), refers to networks of digital image modalities, work and viewing stations, and storage units that are connected to each other by image data communication structures and are controlled by appropriate image and data management (Meyer-Ebrecht, 1994). The implementation of PACS is an attempt to solve a major problem of diagnostic medicine: to store a huge archive of radiographs in such a manner that access to the images becomes as rapid and efficient as access to data and text in office computer systems.

For years, photographic film has been considered the "gold standard" for presentation, transport, and storage of image information. However, the sheer number of films produced (in large hospitals about 1,000 images are produced daily) creates several problems (Meyer-Ebrecht, 1994). A considerable amount of effort is required to make films available for daily practice and to archive them so they are available within a reasonable amount of time. An archived image must be available, within an acceptable period of delay, at any given time for a period of at least five years. Radiographic film archives of several million images can occupy a considerable amount of space and the large number of films may preclude timely access to urgently required

images. In addition, films cannot be simultaneously available at different places for consultation. Substitution of digital images for films solves many problems of storage and retrieval of radiographic images. All diagnostic workstations, where images are produced and evaluated, are connected with the digital archive by way of digital networks. Physical retrieval and transportation of radiographic films (requiring considerable manpower) becomes unnecessary; digital networks permit timely access to radiographic images simultaneously at multiple locations, regardless of whether they have just been generated or have been archived for many years. (Meyer-Ebrecht, 1994).

A PACS consists of four components: (1) image acquisition devices; (2) a network for transmission and distribution of images; (3) workstations for image display and interpretation; and (4) image storage and retrieval systems; (Nissen-Meyer, Fink, Pleier & Becker, 1996; Hynes et al., 1997).

An image acquisition device serves as the point of entry for images into the PACS (Tucker et al., 1995a). In computed radiography (CR), which was introduced by Fugi Photo Film Co., Ltd. in 1983, digital radiographic images are produced directly (Sonada, Takano, Miyahara & Kato, 1983) using a storage phosphor system (SPS). SPS employs a re-usable phosphor-coated film, which is sensitive to x-radiation. CR is compatible with most conventional x-ray imaging equipment and has a wide exposure latitude, producing images with consistent density over a wide range of exposure levels, thereby eliminating over- and under-exposure problems (Miyahara, 1987). Disadvantages of CR include increased “scatter” sensitivity (Tucker, Souto & Barnes 1993), limited spatial resolution (Kato, 1994) and increased cost (Tucker et al., 1995a).

Image distribution refers to movement of a radiographic image from one location to another, i.e. from an acquisition device or storage device to one or more clinical workstations

(Tucker et al., 1995a). Image distribution may be accomplished using a Hospital Information System (HIS), Radiology Information System (RIS) or Local Area Network (LAN). Optimizing image distribution is a tradeoff between expense and bandwidth. Increased bandwidth permits more rapid transmission of images and enhances network capacity (Goldberg, 1996). Important factors to be considered include the anticipated number of images to be transmitted, the case mix (which determines the average size of individual files), the required turnaround time, and periods of peak activity. Consideration of peak activity is important to avoid "bottlenecks" that may result from periods of increased activity during one or more portions of the day.

Critical to the success of PACS is the physician's ability to derive useful information from digital radiographs, facilitating diagnosis and formation of an appropriate treatment plan (Tucker et al., 1995a). Factors to be considered include ease of use, sufficient number and quality (resolution) of monitors, and the strategic location and reliability of workstations that serve a wide spectrum of users. Distribution of clinical workstations is based on peak clinic activity, the average time required for image review, the geographic layout of the clinic and the location of conference rooms (Smith, Smith & Sauls, 1992; Leckie, Goeringer & Smith, 1993). The American College of Radiology (ACR) developed standards for teleradiology in 1994 (Goldberg, 1996). For most conventional images, the ACR recommends a resolution of 2K X 2K X 12 bits for image acquisition and display. Use of dual monitors permits easy side-by-side comparison of current and previously obtained images. Interactive controls offer the opportunity to adjust contrast, brightness, magnification, and position of images and to perform accurate measurements (Gillespy & Rowberg, 1994; Goldberg, 1996). To simplify the image selection process, a limited view of the image database should be provided; it should be targeted to the primary clinical procedure accomplished where the workstation is used. The elapsed time

between selection of an image and the appearance of that image on the display should be minimal (ideally less than five seconds). Retrieval of images on an ad hoc basis during the day could potentially overwhelm the system if multiple users request archived images simultaneously (Smith, Smith, Bender, Carter, Kim, Cawthon, Leckie, Weiser, Romlein & Goeringer, 1995). To prevent such an occurrence, an "intelligent prefetch" may be accomplished: a clinic appointment list may be provided to the archive system by way of the HIS or RIS, so that images may be dearchived during the preceding night and transmitted to a short-term storage system, enabling timely retrieval the next day. Finally, radiographic interpretation (Tucker et al., 1995a) and image annotation, including the patient's demographic and examination information (Goldberg, 1996) should be included and viewed with all images, in accordance with ACR guidelines.

Long-term storage and retrieval of digital images presents a significant challenge in PACS due to the sizeable amount of information involved. One digitized page of text requires a data set of thousands of bytes, whereas a digital radiograph requires a data set of millions of bytes (Meyer-Ebrecht, 1994). A typical chest x-ray, for example, requires at least 2000 X 2000 pixels and necessitates the use of at least 10 bits to record the optical density of each pixel. Mammograms and bone radiographs, which require greater sharpness of detail, may require a data set of not less than 5 mb (Seely, Fisher, Stempski, Borgstrom, Bjelland, & Capp, 1987). Since the data must be stored for at least five years and indefinitely for mammograms (Smith et al., 1995), and since as many as 2 million images may be produced annually in a typical hospital (Meyer-Ebrecht, 1994), the storage system must accommodate 10 tb of data. Storage and retrieval solutions for these giant data sets must be technically and financially practical for the treatment facility and must include consideration of the institution's short- and long-term PACS plans. Images may be archived in a database associated with the individual workstation,

permitting immediate access for the duration of the patient's stay at the hospital. Upon discharge of the patient, long-term management and storage of images may be accomplished by a separate archive system either within the department of radiology or at a centralized storage facility. With the introduction of laser-scanned optical storage disks in the 1970's, storage of several gb of data became possible. Today, double-sided optical disks are stored in "juke-box"-like disk changers, which occupy a fraction of the space required to store conventional radiographic films (Meyer-Ebrecht, 1994).

Important PACS design concepts include standardization, open architecture, connectivity and reliability (Huang & Taira, 1992). To minimize the need to develop its own software and to maximize the portability of the PACS to other computer platforms, a treatment facility should incorporate as many industry standards as possible. Further, an open network design architecture permits a standardized method for data exchange between diverse systems. In this era of rapid advances in computer technology, a closed architecture would hinder efforts to upgrade the system. Reliability and redundancy are important considerations due to the fact that a PACS has a myriad of components (thus, the probability of a component failing is high). Since PACS manages and displays crucial patient information, it cannot be inoperable for extended periods of time. Finally, system security is a major concern due to medico-legal issues regarding patient confidentiality. Most PACS have mechanisms to control access to images and patients' demographic and examination information. These include account control (use of accounts and passwords) and privilege control (granting or revoking access to specific images or data).

Conditions which Prompted the Study

The potential benefits of PACS include both quantitative and qualitative improvements in the practice of radiology (Siegel & Brown, 1994). PACS could potentially replace traditional

film-based techniques, leading to a "filmless" radiology department, where users have rapid access to radiological images both within a medical treatment facility and from remote locations (teleradiology). Realization of this scenario, however, is dependent upon several factors, including continued improvements in the performance of system hardware and software, decreased system costs, and acceptance by medical personnel (Siegel & Brown, 1994). Some radiologists view PACS as an exciting innovation that will enhance and expand the practice of radiology; others view it as an expensive technology with marginal benefits (Dure-Smith & Fymat, 1997).

Madigan Army Medical Center (MAMC) was the first U.S. Army site for installation of a PACS under the Medical Diagnostic Imaging Support (MDIS) system contract for the U.S. Department of Defense (Smith et al., 1995). Clinical operations began in March 1992, with the goal of achieving 90 to 95 percent filmless operations upon complete implementation. Smith et al. (1995) report that system effectiveness and performance have been good with regard to workload throughput and reliability. Clinical physicians readily accept this new technology; radiologists, however, are less enthusiastic about the use of clinical workstations, presumably because MAMC is still in the process of implementing the full complement of hardware and software features.

Planning for a PACS at Walter Reed Army Medical Center (WRAMC) began in January, 1994. Implementation of the first phase of the system occurred in February, 1997 at a cost of approximately $4 million. The current PACS hardware includes three diagnostic workstations ("4A's") for use by radiologists, ten clinical review stations ("2C's") for use by other physicians, a Fugi AC-3CS processor, a Computer Radiology Acquisition Workstation (CRAW), an Interim Storage Unit (ISU), and an Optical Disk Jukebox (ODJ) long-term storage unit. Future plans call

for installation of review stations in each hospital clinic. Digital images are currently stored for outpatient clinics, the intensive care unit (ICU), and the emergency department (ED). Future upgrades to the PACS will permit storage of images for Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound, Nuclear Medicine, and Orthopaedics.

The process of obtaining a digital radiograph is as follows: a physician orders a radiograph using the Composite Health Care System (CHCS), an element of the hospital information system (HIS), which records and transmits patient information and data. Upon arrival at the radiology department, the patient is escorted to an examination room and the radiology examination is performed using a reusable, phosphorous-coated imaging plate in lieu of conventional x-ray film. Patient demographic information is transferred by way of the HIS to a patient terminal (PT), shown in Figure 1. The information is entered into a Medical Digital Imaging Support system (MDIS, General Electric Corporation) and is then transmitted to an identification terminal (IDT). Here, patient demographic information is checked for accuracy. The exposed imaging plate is placed into the Fugi AC-3CS processor (equipped with a "stacker" to accommodate four plates simultaneously) which pre-scans and processes the radiographic image (see Figure 2). Patient identification data and the radiographic image are transferred to the CRAW (see Figure 1), where a quality control senior radiology technician verifies the patient data, reviews the image, makes appropriate adjustments to enhance contrast and position, and sends the data and image electronically to the ISU. Here, they are available for review by a radiologist at a 4A workstation, as shown in Figure 3. The image is then transferred electronically to the ODJ for long-term storage and future retrieval at a 2C viewing station (see Figure 4). The ODJ contains 100 removable optical disks (twelve-inch platters). Each optical disk can store the equivalent of about 100,000 chest radiographs.

The Chief, Department of Radiology, has expressed interest in an evaluation of the costs and benefits of the PACS at WRAMC. In deciding to implement the system in February 1997, management followed an industry trend that was supported by favorable results of the system at MAMC. It is now appropriate to evaluate the efficacy of the PACS compared to a conventional film-based system for radiology. Hospital executives request a report on the return for the sizeable investment in PACS.

Research Questions

The primary research questions addressed in this study are: (a) How does the cost of the PACS compare with the cost of conventional film-based radiology at WRAMC? (b) What are the benefits (as perceived by clinicians) of the PACS at WRAMC? (c) Are WRAMC physicians satisfied with the PACS? (d) What recommendations can be made for future courses of action regarding full implementation of the PACS at WRAMC?

Literature Review

In 1993, the United States spent more than $900 billion (more than 14 percent of our gross national product (GNP) on health care (Feldstein, 1994), and medical expenditures are rising at a rate of 11 to 12 percent each year (Letsch, 1993). If this rate continues, health care spending could reach $1.6 trillion (18 percent of our GNP) by the turn of the century (Feldstein, 1994).

Advances in medical science and health care technology since the end of World War II have fueled growth in health care costs (Williams & Torrens, 1993). New methods of diagnosis and treatment have stimulated demand for medical treatment and providers of health care (both hospitals and physicians) have responded to the increased demand for care (Feldstein, 1994). Until recently, there were few incentives for hospitals to contain costs; health care facilities

concentrated on generating income and could be classified as "revenue centers." With the implementation of a new Medicare hospital payment system in 1983, hospitals were no longer reimbursed according to their expenses. Instead, fixed costs were established for each diagnostic admission, referred to as diagnostic related groups (DRG). Hospitals, therefore, began to focus on limiting expenses and became "cost centers."

Diffusion refers to the spread of a technology into society once it is developed (Williams & Torrens, 1993). In essence, it is the life cycle of technology including entry, adoption, widespread use, and final obsolescence of an invention. The public, of course, is concerned about access to new and beneficial procedures and devices. In contrast, payers (including private insurance companies and federal and state governments), are more concerned with assessing the costs, benefits and efficacy of new technology before it is adopted (Williams & Torrens, 1993).

Today, health care facilities are confronted with a myriad of new medical technologies that are presumed to enhance therapy, diagnosis, care or infrastructure (Van Gennip & Gremy, 1993). Since financial resources are limited, hospitals cannot adopt all of these innovations. Therefore, health care decision-makers must consider costs and benefits in the selection of new technology.

Technology assessment provides insight into the costs and effectiveness of technology (Van Gennip & Gremy, 1993). Although many methods of technology assessment focus primarily on safety and efficacy, cost-effectiveness analysis (CEA) has become increasingly popular, since it is apparent that when a given technology is adopted, there are economic constraints that require trade-offs (Warner & Luce, 1982).

Warner and Luce (1982) describe a framework for conducting a CEA: (a) define the problem and objectives; (b) identify alternatives to address the problem; (c) identify, measure

and value costs and benefits; (d) compare alternatives; and (e) present the findings to stakeholders. Technology assessments that follow this framework are problem-oriented, rather than technology-oriented. Competing technologies are evaluated based on their appropriateness in solving the defined problem (Van Gennip & Gremy, 1993).

Because of the volume of data managed, the required quality of images displayed, the speed of transmission and the necessity of high-tech equipment, PACS require a substantial financial sacrifice (Van Gennip & Bakker, 1993). Hence, it behooves hospital administrators to weigh the costs and benefits before deciding to invest in this technology. The purpose of technology assessment of PACS is to establish the need for the technology, provide a measure of its function, and identify the costs and benefits associated with implementation of the system (Crowe, 1992). Technology assessment, therefore, seeks "to apply economics to cost and rationality to choice" (Wells, Garrett & Jackson, 1991, p.93).

CEA is widely used as a tool for technology assessment (van Gennip & Bakker, 1993). It implies that the cost of an innovation may be compared to its effectiveness and that the latter is not (*per se*) expressed in monetary units (Warner & Luce, 1982). Most CEA studies define effectiveness in terms of health care outcomes, such as dollars per year of life saved. However, Donobedian (1982) defines effectiveness much more broadly, including benefits in the process.

The concept of the "technological imperative" assumes that simply because a technology exists, it will be adopted and used. Crowe (1992) asserts that this is not necessarily true, and that the history of technology is littered with brilliant ideas that, for one reason or another, were never adopted. Crowe (1992) examined the features of a technology which will lead to its widespread introduction and acceptance: (a) it must fulfill a profound need of a large group of potential

users; (b) it must perform a function better than existing technology; and (c) it must be available at the same or lower cost than existing systems.

Technology assessment enables hospital administrators to make informed decisions regarding allocation of scarce resources. Drummond, Stoddard and Torrance (1987) emphasized the need for assessment and the concept of "opportunity costs." In an arena of constrained resources, those devoted to one technology are denied to another. Technology assessment permits comparison of competing technologies on a uniform basis with regard to need, functionality, costs, and benefits (Crowe, 1992). To be accepted, a technology must be effective, economic, appropriate and needed (Wells et al., 1991).

Determining the need for a technology involves consideration of subjective factors (Crowe, 1992). Most important of these is perceived or demonstrated dissatisfaction with alternative systems. (With regard to PACS, the only alternative is use of conventional radiographic film.) The level of dissatisfaction must be such that employees are willing to endure the inconvenience that accompanies introduction of new technology and the associated "learning curve."

Functional assessment is a method of determining if a new technology is capable of performing a task(s) better (e.g. faster, more efficiently, and more cost-effectively) than an alternative system (Crowe, 1992). Performance evaluation may be complicated by the introduction of improved hardware and new techniques (the "moving target" phenomenon). Assessment is, therefore, most challenging in the early days of new technology, when the tempo for technical change is rapid and there is compelling pressure for acquisition because of "apparently self-evident advantages" (Wells et al., 1991, p. 94).

Hospital administrators demand performance of cost-effectiveness analyses before making an investment in PACS (Crowe, 1992). Some studies (Andriessen, Ter Haar Romeny, Binkhuysen & Van der Horst-Bruinsma, 1989; Warburton, Fisher & Nosil, 1990; Van Gennip, Bakker & Greberman, 1992) have determined that the cost of PACS is higher than conventional film systems. However, costs must be examined in relation to expected benefits of PACS (Crowe, 1992). Benefits peculiar to PACS are presented in Table 1. Crowe (1992, p.185) argued that "far too much attention has been paid to the itemization of costs of PACS systems, without sufficient attention being paid to the discrimination of benefits." Cost-benefit assessment of PACS, therefore, involves far more than financial considerations alone (Strickland, 1996); it should include not only an examination of costs, but also effectiveness, economy, and appropriateness. The net result should be an increase in the health of the patient population served (Wells et al., 1991).

PACS may offer a medical treatment facility the promise of lower operating costs, increased efficiency, and improved quality of care (Langlotz, Even-Shoshan, Seshadri, Brickman, Kishore, Kundel & Schwartz, 1995). As the technical quality of PACS improves and large-scale, facility-wide implementation becomes feasible and more likely, hospital administrators have become interested in quantifying the costs and benefits of this new technology. From a technical standpoint, PACS clearly can replace film-based technology (Huda, Honeyman, Frost & Staab, 1996). However, it is important to consider the economic impact of implementing PACS. Past experience shows that the benefits of new technology may be overshadowed by substantial increases in cost (Evans, 1989). Indeed, implementation of PACS has sometimes been postponed due to the lack of a clear demonstration of the cost-effectiveness of this technology (Straub & Gur, 1990). Radiology's reliance on costly technology makes it an

obvious target for budget conscious health care administrators (Becker & Arenson, 1994). There is increased interest, therefore, in conducting economic evaluations of PACS to determine their cost-effectiveness. Hilsenrath, Smith and Berbaum (1994) state:

> Profitability is increasingly used as a criterion for investment in health care, owing to economic pressures that limit the scope for cross-subsidization. Profits will erode if capital expenditures do not ultimately reduce costs, or alternatively, lead to an equivalent or greater increase in revenues.

Traditional cost analyses of PACS have focused solely on comparing the capital and operating costs of implementing this system with the direct (actual) costs of a typical film-based system (Straub & Gur, 1990). The major savings expected from a PACS may be attributed to supply (film and chemicals), film-handling personnel, and storage space (Langlotz et al., 1995; Huda et al., 1996). Additional savings may be realized from reduction in the amount of hazardous material produced (e.g., spent developer and fixer solutions) and its disposal. Most studies, however, have failed to consider hidden or indirect costs of film-based systems that may result from inefficiencies such as lost films, duplicated (repeated) examinations, and lack of timely access to diagnostic images and reports (Straub & Gur, 1990, Langlotz et al., 1995). Indirect costs are difficult to quantify (Strickland, 1996), but may be assessed by surveying the medical staff. Straub and Gur (1990, p.614) state that "input from physicians can provide valuable, although not empirical, evidence of the general importance and magnitude of the indirect costs of the system." Indeed, significant cost savings may be realized by implementation of PACS, as a result of more timely access to images and reports, permitting more timely decisions regarding patient treatment. The resultant increase in efficiency could substantially decrease costs, an attractive outcome in a managed care environment. Studies by Tucker et al.

(1995a), Langlotz et al. (1995), and Huda et al. (1996) determined that the cost of a PACS is, indeed, offset by savings from eliminating the cost of film production and management.

Langlotz et al. (1995) described three types of economic analyses: (a) cost-benefit, (b) cost-effectiveness, and (c) cost identification. Cost-benefit analysis compares the costs of medical intervention to its benefits, in monetary units (e.g., dollars). Cost-effectiveness analysis is similar, but costs and benefits are not necessarily expressed in the same units, since medical outcomes often cannot be expressed in units of currency. Results of cost-effectiveness analysis are most often reported as a ratio of the number of dollars spent per unit of outcome (e.g., dollars per year of life saved). Cost-identification analysis is less complex; it simply lists costs without consideration of outcomes. Cost-identification is useful in comparing the costs of alternative methods for providing the same service. Most economic studies of PACS are, therefore, characterized as cost-identification analyses that examine direct costs in a radiology department (Langlotz et al., 1995). Department expenditures are used to estimate the cost of film-based radiography, and an analysis of departmental operations affords an estimate of equipment, supplies, and personnel costs for the operation of a PACS. The direct costs of PACS and film-based radiology are presented in Table 2 and Table 3.

Purpose

The purpose of the current study is (1) to identify and measure the direct costs of complete implementation of the PACS at WRAMC using cost identification analysis; (2) to compare the direct costs of the PACS and conventional film-based radiology; (3) to determine the level of healthcare provider satisfaction with the PACS; and (4) to present the findings and recommendations to the Chief, Department of Radiology, to assist him in determining the cost-

efficiency of the PACS at WRAMC and to suggest future courses of action regarding expansion of the sytem at WRAMC.

The working hypothesis of this study is that the PACS at WRAMC is a cost-efficient alternative to film-based radiology (based on cost identification analysis) and that healthcare providers at WRAMC are satisfied with the system. Further, overall satisfaction with the PACS is a function of ten specific factors (the first ten questions on the survey instrument).

Method and Procedures

This research was a retrospective, predictive analysis of the PACS system at WRAMC.

The PACS at WRAMC was assessed in a manner patterned after that described by Straub and Gur (1990). Two methods were used in the assessment of the PACS at WRAMC: (1) cost identification, and (2) healthcare provider satisfaction. Direct costs of PACS and traditional film-based radiology, as described in Table 2 and Table 3, were determined from a quotation from Agfa Medical, Division of Bayer, Inc. and historical records (purchase requests and document registers) supplied by the Department of Radiology. Provider satisfaction with the PACS was measured using the survey instrument in Appendix A.

A survey must include a representative sample of the population studied. In the present study, the population consisted of all healthcare providers who may utilize the PACS at WRAMC. The sample included providers assigned to departments that are major users of the PACS.

The most appropriate applications of surveys are those in which the sample is composed of respondents who are "uniquely qualified to provide the desired information" (Cooper & Emory, 1995, p. 270). Therefore, the instrument, an eleven-item questionnaire, was distributed to practitioners assigned to departments that are major users of the system: Radiology, Emergency,

Medicine, Surgical Intensive Care, Cardiothoracic Surgery, Pulmonary, and Urology. The survey questions were closed end. Responses were based on a modified five-point Likert scale (Likert, 1932), substituting numeric values for semantic labels. Numeric values ranged from 1 ("strongly agree") to 5 ("strongly disagree"). Respondents with no opinion on a particular question were afforded the opportunity to select a neutral midpoint (a score of 3).

In the development and administration of a survey tool, the issues of validity and reliability must be addressed. A method to determine content validity is to have a panel of individuals make a judgement regarding the extent to which an instrument provides adequate coverage of the topic under study (Cooper & Emory, 1995). Therefore, the instrument was evaluated and critiqued by representatives from the Department of Radiology and reviewed by a representative from the Department of Nursing Education and Research.

Content Validity of the survey was evaluated using procedures described by Waltz, Strickland and Lentz (1984). When two judges are employed, the Index of Content Validity (CVI) is used to quantify the degree of agreement between the experts. To compute the CVI, the experts are given the objectives of the survey and the survey items. They are requested to rate the relevance of each item to the objectives using a four point scale: (1) not relevant, (2) somewhat relevant, (3) quite relevant, and (4) very relevant. The CVI is defined as the proportion of items given a rating of quite relevant and very relevant by both of the raters. If all items receive quite relevant or very relevant ratings by both raters, the CVI is 1.00, indicating perfect interrater agreement. A CVI of .70 was required to establish content validity of the survey instrument. A copy of the instrument used to establish content validity is presented in Appendix B. Survey questions were grouped into three categories: benefits to the diagnostician (radiologist), benefits

to the referring physician, and benefits to the patient. Judges were requested to evaluate the relevance of each question to the appropriate category.

A measure that affords consistent results is considered reliable. A reliable measure is free from random or unstable error (Cooper & Emory, 1995). Internal reliability can be assessed using Cronbach's coefficient alpha. The acceptable criterion for high internal reliability is Cronbach $\alpha \geq .70$ (Cronbach, 1951). This test was performed to determine the reliability of the survey instrument.

Pretesting permits identification of problems or weaknesses in a survey instrument before data collection begins. Colleagues, respondent surrogates, or actual respondents evaluate and refine the questionnaire. Pretesting of the survey instrument was accomplished by surveying radiologists at WRAMC and soliciting feedback.

Data from the survey was entered into SPSS®, a statistical software package. Missing values were replaced with the series mean. Descriptive statistics (means and standard deviations) were computed for all continuous variables (all eleven questions on the survey instrument). A correlation matrix was constructed; correlations between the mean scores of providers' responses to the first ten survey questions and the single question of overall satisfaction (question 11 on the survey instrument) were determined. A stepwise multiple regression analysis was accomplished to determine the contribution of each of the ten items to overall satisfaction. The dependent variable was overall satisfaction and the independent variables were each of the other ten items included in the survey instrument. An alpha level of .05 was selected for the regression analysis.

Results

Equipment required to complete implementation of the PACS at WRAMC is presented in Table 4, which was derived from a quotation to the Department of Radiology, WRAMC, from Agfa Medical, Division of Bayer, Inc., dated 31 March 1998. The annual cost to complete implementation of the PACS at WRAMC is presented in Tables 5 and 6. These data were also supplied by Agfa Medical, Divison of Bayer, Inc. The annual cost of continuing to use film-based radiology is presented in Table 7, which is based on data supplied by the Department of Radiology, WRAMC. The total annual operating cost of the PACS for the first year is $2,485,924.80. In subsequent years, the total annual operating cost declines from a high of $2,774,724.80 in year 2 to a low of $1,812,861.80 in year 8 (due to changes in the cost of maintenance and a full time on-site field service engineer). In contrast, the total annual operating cost of film-based radiology amounts to $913,665.97 (based on fiscal year 1997 data).

The Index of Content Validity (CVI) for the survey instrument was .95, indicating a high degree of interrater agreement. This value exceeded the minimum value of .70 required to establish content validity.

The survey was administered during the period 9 February - 27 March 1998 to healthcare providers assigned to the departments previously described. Distribution of the survey to practitioners working in departments that are major users of the PACS assured that the sample was representative of the population. Of 132 surveys distributed, 119 were completed, representing a 90% rate of return. The high rate of return may be attributed to the fact that the surveys were distributed, completed, and returned during scheduled departmental staff meetings. The high rate of return, the low rate of missing data (.45%) and the representativeness of the sample contribute to the reliability and usefulness of the survey instrument.

Cronbach's coefficient alpha for the survey instrument was determined to be .7928. This exceeded the acceptable criterion for high internal reliability.

Demographics of the survey participants are presented in Table 8. The majority are male (83%) and are on active duty in the military (92%), with a varying degree of experience as medical care providers.

Descriptive statistics for each of the eleven continuous variables are presented in Table 9. Generally, survey participants expressed moderate to strong agreement with the survey items, although degree of agreement ranged the entire spectrum from "strongly agree" to "strongly disagree" for some items. They agreed highly that the PACS provides rapid access to radiographic images (question 1, $\underline{M} = 1.47$). Likewise, they agreed that the ability to review multiple images simultaneously in more than one location (that is, the presence of multiple viewing stations) is important in their clinical practice (question 6, $\underline{M} = 1.76$). The participants are confident in their diagnoses using digital images (question 10, $\underline{M} = 1.98$) and they agree that the PACS improves the quality of care delivered (question 4, $\underline{M} = 2.02$). Further, the providers agree that the PACS increases the efficiency of clinical practice (question 5, $\underline{M} = 2.03$). They expressed moderate agreement with the remainder of the survey items. Overall satisfaction with the performance of the PACS at WRAMC was moderate (question 11, $\underline{M} = 2.17$).

Overall satisfaction by department varied widely and is presented in Table 10. Some departments, including Radiology, Emergency, Surgical Intensive Care, and Medicine are quite satisfied with the PACS. Other departments are less satisfied.

Overall satisfaction also varied by type of healthcare provider (see Table 11). For purposes of this analysis, survey participants were categorized into two groups. One group, labeled "student," included those enrolled in undergraduate or graduate medical education (i.e.,

medical students, interns, and residents). The other group, labeled "staff," included attending and staff physicians, as well as other healthcare providers (e.g., physician assistants). Survey participants in the "student" category exhibited a higher level of overall satisfaction ($M = 2.03$) than did those in the "staff" category ($M = 2.44$).

Correlations between mean scores of provider responses to questions 1 through 10 and overall satisfaction (question 11) are presented in Table 12. The correlation matrix reveals a positive relationship between the mean scores of providers' responses to all but one of the first ten survey questions and the single question of overall satisfaction. (There is a weak negative correlation with question 2.) All correlations with question 11 are significant at the .01 level except for question 2. There is a strong, positive relationship between overall satisfaction and question 1 ($r = .399$), question 4 ($r = .433$), question 5 ($r = .513$), question 8 ($r =.585$), question 9 ($r = .505$), and question 10 ($r = .537$).

Results of the stepwise multiple regression analysis are presented in Tables 13, 14 and 15. Analysis of the regression revealed that the most significant factor associated with overall satisfaction with the PACS at WRAMC was the "user friendliness" (i.e., the ease of use) of the system (question 8), and this resulted in a shared variance, $R^2 = .342$ (a highly predictive value) with F (1, 117) = 60.812, $p < .0001$. Three other variables that contributed significantly to the shared variance were questions 10, 5 and 9, which, when included in model 4, resulted in a shared variance, $R^2 = .557$ with F (4, 114) = 35.847, $p < .0001$. Thus, overall satisfaction with the PACS at WRAMC can be predicted from a model consisting of provider perceptions of (1) the "user friendliness" of the PACS, (2) its effect on the efficiency of clinical practice, (3) its reliability, and (4) providers' confidence in diagnosis using the PACS.

Responses to two additional survey questions are presented in Table 16. The majority of providers surveyed (87%) desire to have a dedicated review station located in their clinical areas and 92% would like to have radiographic images and reports displayed on their personal computers.

Provider written comments are presented in Table 17. Most providers expressed a desire to have more viewing stations located in close proximity to their clinical areas. Two providers reported difficulty in retrieving archived images. One expressed a keen desire to have the opportunity to view images and reports on his personal computer.

Discussion

Although the cost identification methodology employed in this study is not sophisticated, the data do identify the key financial issues associated with further implementation of the PACS at WRAMC. Existing capital equipment represents a "sunk" cost and is not included in this analysis.

Huda et al. (1996) found that the major savings that can be realized by implementing a PACS are from supplies (film and chemicals) and employee savings. The present study reveals that film-based radiology at WRAMC costs $548,151.97 annually in supply and production costs and $172,314.00 in staff costs (see Table 7). No new capital equipment for film-based radiology has been proposed. The total annual supply, production and personnel cost of film-based radiology at WRAMC is, therefore, $720,465.97.

Complete implementation of the PACS at WRAMC would result in a saving of 4,830 square feet of storage space (film-based radiology and PACS require 4,878 and 48 square feet, respectively). The annual cost of one square foot of storage space ranges from $10 to $140 (Becker et al., 1994). In the metropolitan Washington, DC area, the rental price for commercial

property varies greatly, but has been reported as $40 per square foot per annum in downtown office buildings (Hunt & Weichert Commercial Realtors, 1998). Therefore, the annual storage cost of film-based radiology could potentially amount to $193,200. Thus, the total annual operating cost of film-based radiology at WRAMC is $913,665.97 (see table 7).

Cost-analyses differ in reports of the direct costs of PACS and film-based radiology, and these differences cannot be explained by variations in the size of the medical facility studied or the number of examinations performed (Becker & Arenson 1994). Variations in the cost of space, material, and personnel at least partially account for the differences. Also, the purchase price of capital equipment, maintenance costs, and amortization costs may vary in different locations. The most substantial cost of the PACS in the present study is that for maintenance and a full time service engineer.

Studies by Tucker et al. (1995a) and Huda et al. (1996) found that savings from the elimination of conventional film production and management offset the total cost of a PACS. In contrast, the present study determined that, although the PACS does afford substantial savings in film and production costs, the overall total annual cost of complete implementation of the PACS at WRAMC exceeds the total annual cost of film-based radiology by $1,572,258.83 in year 1 and between $1,861,058.83 and $899,195.83 in years 2 through 8. Huda et al. (1996) developed workstations in-house at reduced cost ($50,000 each) and did not include the cost of purchasing remote review stations, since they planned to continue use of existing image display stations that were installed previously. (These represented "sunk" costs.) WRAMC will require the purchase of nine D2 Diagnostic workstations (equivalent to existing 2C viewing stations) for the Pulmonary and Orthopaedic Departments, twelve D4 workstations (equivalent to existing 4C workstations) for Radiology, forty-two R2 clinical review stations, and nine R1 technologist

review stations at an annual cost of $844,505.88 (see Tables 5 and 6). This would enable providers to view images in their respective clinics, a highly desirable procedure as indicated by results of the survey.

Survey results indicate that, although the diagnostic accuracy of digital images may not equal or exceed that of film-based techniques (question 2), physicians at WRAMC are, nonetheless, confident in their diagnoses using digital techniques. The results indicate a moderate overall satisfaction with the PACS at WRAMC. Physicians believe that the system provides rapid access to radiographic images and enhances the quality of care delivered. They greatly value the ability to review images simultaneously (i.e., the presence of multiple viewing stations). Most desire the convenience of having a dedicated review station in their clinic and would like to be able to view reports and images on their personal computers.

As noted above, overall satisfaction by department varied greatly. The departments of Radiology, Emergency, Surgical Intensive Care and Medicine enjoy ready access to viewing stations in their clinics and hence exhibit a high degree of satisfaction with the PACS. Access for other departments, especially and Urology, is problematic; they do not have easy access to viewing stations and so a lower level of satisfaction may be expected.

Overall satisfaction also varied by type of provider. Students, who are usually younger and are part of a generation that grew up with computers, can be expected to be more receptive to the introduction of new technology, including PACS. Seasoned staff physicians, in contrast, may face a steep "learning curve." These findings are in agreement with those of Smith et al. (1995), who reported that radiology residents at MAMC were nearly unanimous in their approval of PACS. Staff radiologists at that facility who use the workstations most frequently are typically

older and had never used a computer before the PACS was installed. Nonetheless, even senior clinicians have learned to use the system effectively.

The correlation results indicate that provider satisfaction with the PACS is strongly correlated with provider perceptions regarding ready access to radiographs, the quality of care delivered, clinical efficiency, ease of use, reliability, and confidence in arriving at an appropriate diagnosis using digital images.

The current study determined that, based on regression analysis, the major factors contributing to overall satisfaction with the PACS at WRAMC are its ease of use, its effect on the efficiency of clinical practice, its reliability, and providers' confidence in diagnosis using the PACS.

Leckie et al. (1993) reported that a consistent observation of all new users of a PACS is that the system is easy to understand and learn. Tucker et al. (1995a) also found that the response from providers using viewing stations was uniformly positive. They liked the convenience and easy access to images and reports provided by the PACS. Healthcare providers at WRAMC agree with this observation. Smith et al. (1995) state that a training program employing vendor-supplied computer technicians and trainers in a small group setting affords clinicians a basic understanding of PACS and workstation functions. He concludes that additional "hands-on" practice, coaching from knowledgeable colleagues, and time and experience will eventually lead to full utilization of the system in clinical practice.

Tucker et al. (1995a) reported that one of the direct benefits of a PACS is improved efficiency for physicians, technologists and staff. They stated that repeated examinations may result from improper technique, positioning errors, lost or misfiled radiographs, or poor technical film quality. The rate of missing radiographic films may be as high as 30% in some hospitals

(Osteaux, Van den Broeck, Verhelle & de Mey, 1996). This may have profound medical and medico-legal implications. Repeated examinations, regardless of cause, are not desirable (Straub & Gur, 1990). Repeated examinations expose patients to unnecessary ionizing radiation and treatment delay, and can result in lost revenue and inefficiency for the hospital. Digital radiography can reduce the number of repeated examinations by eliminating over- and underexposure problems, and, by virtue of its image management capabilities, prevent mishandling and film loss. Therefore, with the exception of repeated studies due to positioning errors, PACS can effectively eliminate common radiographic problems and improve the efficiency of the radiology department. Tucker et al. (1995a) reported that at the University of Alabama Hospitals and Clinics, the frequency of repeated examinations decreased from 15% to 3% upon implementation of computed radiography. Smith et al. (1995) estimate a time savings of one hour per week per clinician due to enhanced image and report availability with PACS. This translates to saving 20,000 hours annually in a hospital that employs 400 physicians! Physicians at WRAMC agree that the PACS increases the efficiency of their clinical practice and improves the quality of care delivered.

The third major factor contributing to overall satisfaction with the PACS at WRAMC is system reliability. A hospital operates 24 hours per day and past experience indicates that even a 95% system availability is barely sufficient for user acceptance (Smith et al., 1995). Interruption of clinical services could have dire life or death consequences. Smith et al. (1995) recommend that a PACS contract should require 99% system availability and include detailed plans for crisis management and operations when the system is "down." They report a high degree of reliability (99.7%) of the PACS at MAMC. Providers at WRAMC moderately agree that the PACS is reliable ($\underline{M} = 2.21$).

The other major factor contributing to overall satisfaction is providers' confidence in diagnosis using the PACS. Healthcare providers at WRAMC are dedicated to providing optimal care for all beneficiaries, and arriving at an appropriate diagnosis is key to providing top quality care. Providers at WRAMC are confident in their diagnoses using the PACS and they believe that the system enhances the quality of care provided at this institution.

Conclusion and Recommendations

PACS can be considered an extension of a hospital's information system (HIS), in which data may be obtained, stored, retrieved and displayed in digital format. However, the volume of data created by a PACS is typically much greater than that of a typical HIS. Additionally, there are requirements for high quality viewing stations and transmission speed that is several orders higher in magnitude than that required for conventional HIS. As a result, a PACS requires more high-technology equipment and, therefore, a substantial financial investment (Van Gennip & Bakker, 1993). Hence, although prototypes were available in the early 1980's, routine clinical use of PACS has developed slowly. It is no surprise that hospital administrators must weigh the costs and benefits of PACS before deciding to invest in this technology.

Straub and Gur (1990) reported two major barriers to implementation of a PACS: cost/benefit concerns and the belief that the diagnostic accuracy of PACS may not be comparable to that attained using conventional film. The cost identification analysis in the present study focused on identifying direct costs associated with the PACS and conventional film-based radiology. The study confirms that complete implementation of the PACS, as proposed, is indeed expensive. However, Straub and Gur (1990) clearly demonstrated that significant future savings may lie in avoidance of indirect (hidden) costs resulting from rapid, timely access to diagnostic images and reports, and enhanced efficiency of physicians' clinical practice. The present study

confirmed these findings: physicians at WRAMC agree that the PACS provides rapid access to radiographic images and improves efficiency. Further, they believe that the PACS improves the quality of care rendered to patients. Unfortunately, indirect costs are, at best, difficult to quantify. Hence, opinions regarding the total costs and savings of PACS vary widely (Van Gennip & Bakker, 1993). However, a PACS does offer the promise of efficient management of a hospital's increasingly large and complex information base in radiology. Future studies should attempt to quantify the indirect costs that result from less than ideal film archival and communication systems. "Only then can the potential impact of digital PACS on total cost be appreciated, and only then might the financial justification for PACS implementation be rationalized" (Straub & Gur, 1990, p. 616). Because of high cost estimates, many hospitals are reluctant to implement a PACS. Van Gennip and Bakker (1993) suggest that in addition to identifying costs and benefits of a PACS, and before investing in a PACS, healthcare institutions should seriously consider whether a it is the best method to solve problems with storage and distribution of medical image information.

Regarding diagnostic accuracy of PACS, findings in the literature are mixed. According to Huda et al. (1996), limitations of computed radiography include inferior spatial resolution and higher image noise when compared to film-based radiography using the same radiation dose. Likewise, Stormer, Boole, Sund, Weller, and Gitlin (1997) reported that conventional films were generally perceived to be of better quality than screen images and that radiologists were more confident in their diagnoses using conventional film. In contrast, Kido, Ikezoe, Takeuchi, and Kondoh (1994) found no statistically significant difference in performance between film and digital radiography. Kimme-Smith, Aberle, Sayre, Hart, Greaves, Brown, Young, Deseran, Johnson and Johnson (1995) found no statistically significant difference except when computed

radiographs were underexposed. Jonsson, Hannesson, Herrlin, Jonsson, Andersen, and Pettersson (1995) reported that as a result of incorporation of smaller phosphorous particles on imaging plates and the use of high-resolution monitors, digital systems provide adequate diagnostic accuracy. The present study confirmed the findings of the latter researchers: physicians at WRAMC are confident in their diagnoses using digital images.

Because of constrained resources, especially in a managed care environment, with emphasis on minimizing costs, a healthcare institution cannot adopt all medical innovations. Clinicians and healthcare administrators must, therefore, carefully consider costs and benefits in the selection of new technology. They must consider effectiveness, economy, appropriateness, and need. In sum, adoption of a given technology should be based on its appropriateness in solving a defined problem.

The Chief, Department of Radiology, should consider the following when contemplating complete implementation of the PACS at WRAMC:

System reliability is very important to physicians at WRAMC and two critical issues must be considered. First, since a PACS consists of a multitude of components, the probability of a failing component is high. Second, because a PACS manages important patient information, the system cannot be "down" for long periods of time. Redundancy, therefore, is a critical factor in meeting reliability requirements and can greatly enhance system performance at minimal cost (Tucker et al., 1995a). In addition, spare parts should be readily available.

Viewing stations should be decentralized, i.e., located in clinical areas throughout the hospital, to provide easy access to the system. Distribution of viewing stations depends upon the level of clinic activity, the time required to review images, the physical layout of the clinic, and the number and location of conference rooms (Smith et al., 1992; Leckie et al., 1993). Different

departments, therefore, will have varying requirements for viewing stations. Smith et al. (1995) report that at MAMC, the approximate ratio is 3.4 physicians per viewing station. Viewing stations should be located in areas where the ambient light can be regulated to permit optimum conditions for diagnostic procedures (Arenson, Chakraborty & Seshadri, 1990). The survey in the present study indicated that the presence of multiple viewing stations is a major concern for healthcare providers at WRAMC and has a significant impact on satisfaction with the PACS.

A "prefetching" system should be employed to send images from the ODJ to the short-term storage unit the night before scheduled examinations or consultations, permitting timely retrieval the next day. This will prevent potential "bottlenecks" in the system that could result during periods of peak demand, if images were instead retrieved on an ad hoc basis. Providers at MAMC agree that a "prefetching" system is essential for successful filmless operations at that facility (Smith et al., 1995). Likewise, rapid access to radiographic images is very important to healthcare providers at WRAMC.

PACS training is important to ensure optimal patient care and to satisfy potential ethical, risk management, and medico-legal requirements (Protopapas, Siegel, Reiner, Pomerantz, Pickar, Wilson & Hooper, 1996). Ideally, training should accomplish two goals. Firstly, the provider should learn how to use the system to expeditiously retrieve images and reports and to display them on monitors. Secondly, the provider should learn to use the tools available at the viewing station to optimize the images for interpretation, in order to derive an appropriate diagnosis. PACS training should be accomplished individually or in small groups, so that it may be tailored to the provider's individual needs and specialty. Computer-based and on-line training may also be considered. A continuous PACS training program is especially important in a military facility, due to the high rate of personnel turnover (Smith et al., 1995).

One workstation should be dedicated for the purpose of making hardcopy images, using a laser-film printer (see Figure 5). Due to the high turnover of active-duty personnel and their families to other military installations, most of which do not have a PACS, the demand for hardcopy reprints of historical images may be substantial (Smith et al., 1995).

A mechanism for system security should be implemented to ensure confidentiality for patients. This will help to prevent unauthorized access to patients' demographic and examination information.

An open architecture network design permits data exchange between heterogeneous systems (Hunag & Taira, 1992). If two PACS designs cannot communicate with each other, they become isolated and cannot be combined with other systems to develop a hospital-wide or health care system-wide PACS. In addition, computer and communications technology is changing rapidly and even state-of-the-art systems soon become obsolete. A closed architecture network design would preclude system upgradability and inter-connectability between health care facilities. This has significant implications for the Walter Reed Health Care System (WRHCS), which consists of Walter Reed Army Hospital, Dewitt Army Community Hospital, Kimbrough Ambulatory Care Center and numerous satellite facilities. Ideally, the PACS should provide for seamless transfer of digital images throughout the health care system, thus enhancing referral and consultation procedures.

Development of PACS continues to be one of the most challenging tasks in the field of computer engineering, due to the huge volume of digital image data produced, necessitating the introduction of novel architectures and technology (Meyer-Ebrecht, 1994). Early PACS were extremely expensive, unreliable, and had limited image storage capability. Today, technology has improved markedly and PACS can improve the efficiency of delivering healthcare, moderate

operating costs, shorten the time required to obtain, distribute, and retrieve radiographic images, dramatically reduce the number of repeat examinations and lost films, and produce consistent image quality (Hynes et al., 1997; Tucker & McEachern, 1995b). Sorting through a film jacket containing 25 films requires many minutes. Using PACS, all 25 images may be displayed simultaneously and, with the click of a mouse, appropriate ones may be enlarged for comparison.

A PACS can reduce or eliminate requirements for film clerks, dark-room technicians, typists, film storage, film and chemistry costs and, theoretically, lead to substantial savings. However, these savings may be offset by the direct cost of viewing stations, networks, software, computers, archives, and system maintenance. Nonetheless, it is important to consider the harder-to-quantify gains that may be realized across the hospital (Langlotz et al., 1995) due to shorter waiting times, more timely decision making (Dure-Smith & Fymat, 1997) and possibly reduced length of stay (Straub & Gur, 1990).

The trend toward PACS is inevitable and will likely be complete within a decade (Hynes et al., 1997). Some experts (Osteaux et al., 1996) believe that PACS could account for 80% of the radiological business by the year 2000. Delaying implementation is probably unwise, since hospitals that offer the outreach that a PACS provides will have a competitive edge in the marketplace.

This study presented the major benefits that can be anticipated upon complete implementation of a PACS. It also identified the direct costs of the system, as well as those associated with film-based radiology. A PACS can provide a mechanism to solve the problem of preserving, transporting, sorting, reading, storing and retrieving radiographic images and reports in an expeditious and efficient manner. In addition, through implementation of a PACS, a hospital can expect to realize significant cost savings in terms of supplies (film and chemicals),

storage space and personnel required. PACS may also reduce requirements for silver recovery systems and disposal of hazardous materials, including developer and fixer solutions. However, hardware, software, information system, and maintenance costs of a PACS are high. Therefore, it is the task of clinicians and hospital administrators to determine if a PACS is the best method, consistent with their budget, to solve problems with storage and distribution of medical image information, resulting in a net incremental improvement in the health of the population served. They must assess not only cost, but also the value of outcomes, enhanced productivity, and the societal contribution of patients that have been restored to health (Wells et al., 1991).

Table 1

Benefits of PACS

Category	Benefit
Benefits to Diagnostician	improved access to current patient records improved access to patient history records file integrity and speed of retrieval better diagnosis quicker diagnosis/improved productivity
Benefits to Referring Physician	better patient management earlier intervention better outcome reduced length of stay reduced loss of films
Benefits to Patient	reduced radiation exposure shorter examination times fewer re-takes reduced inconvenience reduced chance of adverse reaction from contrast agents
Benefits to Hospital	better communication with physicians better hospital administration improved morale of staff

Note. Adapted from "Overview of Some Methodological Problems in Assessment of PACS," by B.L. Crowe, 1992, International Journal of Biomedical Computing, 30, p. 185.

Table 2

Cost of PACS

1. System (Capital) Costs
    a. Hardware
        (1) Image generating apparatus (CR unit)
        (2) Digital interphases (fiberoptic transducers)
        (3) Workstations (including monitors)
        (4) Viewing Stations
        (5) Digitizer
        (6) Cabling
    b. Software
2. Maintenance (engineering support) for CR, diagnostic displays, archive and server
3. Storage Media (optical disks) and "Jukebox"
4. Archive Loading
5. Supplies
6. Personnel (including PACS technicians)
7. Space for archive

Note. Adapted from "A Cost-Analysis of Computed Radiography and Picture Archiving and Communication Systems in Portable Radiology," by W. Huda, J. C. Honeymoon, M. M. Frost, and E.V. Staab, 1996, Journal of Digital Imaging, 9 (1) p. 41.

Table 3

Cost of Film-Based Radiology

1. System (Capital) Costs
    (a) X-Ray apparatus
    (b) Developers (automatic, manual)
    (c) Viewboxes
2. Film
3. Chemicals
4. Supplies
5. Miscellaneous (e.g. film jackets)
6. Maintenance
7. Personnel (including film librarian and darkroom technician)
8. Space for archive

Note. Adapted from "A Cost-Analysis of Computed Radiography and Picture Archiving and Communication Systems in Portable Radiology," by W. Huda, J. C. Honeymoon, M. M. Frost, and E.V. Staab, 1996, Journal of Digital Imaging, 9 (1) pp. 41-42.

Table 4

Equipment Required to Complete Implementation of PACS at WRAMC (Includes Hardware, Software, Cabling, and Management)

Item	Quantity
QC Workstation Workflow Manager	5
Large AS3000-DLT Base Package	1
DLT Jukebox Media	10
50 GB External RAID for AS3000 Packages	3
Large OS3000 Package	1
IMPAX RS 3000-2P-2K (D2) Diagnostic Workstation (Pulmonary & Orthopaedics)	9
IMPAX RS 3000-4P-2K (D4) Diagnostic Workstation (Radiology)	12
IMPAX RS 5000-2-1K (R2) Clinical Review Station	42
IMPAX RS 5000-1-1K (R1) Technologist's Review Station	9
Web 1000 Server & 30 Licenses (each server supports 100 concurrent users)	1
Modem with Cable	1
RIS Gateway/Interface	1
DIN-PACS Embedded Network	1
DIN-PACS Embedded RIS with Training	1
AFC Industries Work Surfaces with Chair for all Stations	1
Site Management	1
Project Management	1
Field Engineer on-site Acceptance	1

Table 5

Annual Cost of PACS at WRAMC (First Year)

Item	Total Cost ($)
Equipment*	770,287.00
Installation*	48,953.50
Site Preparation*	8,337.38
Uninterruptable Power Supplies*	10,000.00
CDRLs*	6,928.00
TOTAL ANNUAL EQUIPMENT COST	844,505.88
Maintenance	1,634,699.00
Full Time on-site Field Service Engineer	(included in maintenance cost)
TOTAL ANNUAL EQUIPMENT, MAINTENANCE, AND PERSONNEL COSTS	2,479,204.80
Space for Archive (square feet)	
Optical Disk Jukebox	32
ISU	12
Personal Computers (2)	4
Total Square Footage	48
TOTAL ANNUAL STORAGE COST (@ $140 per square foot)	6,720.00
TOTAL ANNUAL COST OF PACS (First Year)	2,485,924.80

Note: "*" indicates the cost has been amortized over an 8-year period.

Table 6

Annual Cost of PACS at WRAMC (Years 2-8)

Year	Equipment	Maintenance & Engineer	Storage	Total Annual Cost ($)
2	844,505.88*	1,923,499.00	6,720.00*	2,774,724.80
3	844,505.88*	1,732,375.00	6,720.00*	2,583,600.80
4	844,505.88*	1,673,444.00	6,720.00*	2,524,669.80
5	844,505.88*	1,240,249.00	6,720.00*	2,091,474.80
6	844,505.88*	1,148,841.00	6,720.00*	2,000,066.80
7	844,505.88*	961,636.00	6,720.00*	1,812,861.80
8	844,505.88*	961,636.00	6,720.00*	1,812,861.80

Note: "*" indicates the cost has been amortized over an 8-year period.

Table 7

Annual Cost of Film-Based Radiology at WRAMC

Item	Quantity	Individual Cost ($)	Total Cost ($)
X-Ray Apparatus	(no new equipment proposed)		0
Developers	(no new equipment proposed)		0
Viewboxes	(no new equipment proposed)		0
Film			463,578.57
Chemicals			17,360.00
Contract for Silver Recovery and Hazardous Waste Disposal			14,000.00
Film Jackets			
Master	26,840	$42 per 100	11,272.80
Report Jackets	23,240	$38 per 100	8831.20
Teaching Files	1,130	$38 per 100	429.40
Inserts	122,000	$70 per 500	17,080.00
Maintenance (Annual contract to clean processors)			15,600.00
Total Annual Supply and Production Cost			548,151.97
Personnel			
File Room Clerk (GS-4)	7 (diagnostic)	19,146	134,022.00
Darkroom Technician (GS-4)	1	19,146	19,146.00
File Room Clerk (GS-4)	1 (therapy)	19,146	19,146.00
Total Personnel Cost			172,314.00
Total Annual Supply, Production and Personnel Cost			720,465.97
Space for Archive			
Diagositic			4366
Radiation Therapy			36
Nuclear Medicine			224
Orthopaedics			252
Total Square Footage			4878
TOTAL ANNUAL STORAGE COST (@ $140 per square foot)			193,200.00
TOTAL ANNUAL COST OF FILM-BASED RADIOLOGY			913,665.97

Table 8

Demographics of Survey Participants

	Number	Percentage (Rounded)
Position		
Medical Student	10	8
Intern	18	15
Resident	39	33
Attending	12	10
Staff	24	20
Other	16	14
Gender		
Male	99	83
Female	17	14
Unknown (unmarked)	3	3
Status		
Active Duty	109	92
Contract	2	2
Other	7	6
Unknown (unmarked)	1	<1

Table 9

Descriptive Statistics for All Continuous Variables (n=119)

Question #	Mean	Standard Deviation	Minimum	Maximum
1	1.47	.66	1	4
2	2.71	1.09	1	5
3	2.21	.96	1	4
4	2.02	.85	1	5
5	2.03	.97	1	5
6	1.76	.96	1	5
7	2.22	.93	1	5
8	2.30	1.02	1	5
9	2.21	.81	1	5
10	1.98	.65	1	5
11	2.17	.87	1	5

Table 10

Overall Satisfaction (Question 11) By Department

Department	Mean	Standard Deviation	Minimum	Maximum
Radiology	2.07	.73	1	4
Emergency	1.58	.51	1	2
Medicine	1.70	.53	1	3
Surgical Intensive Care	1.95	.65	1	4
Cardiothoracic Surgery	2.69	.95	2	5
Pulmonary	2.69	1.01	2	5
Urology	3.00	.78	2	4

Table 11

Overall Satisfaction by Type of Healthcare Provider

Type of Provider	Mean	Standard Deviation	Minimum	Maximum
Student	2.03	.77	1	4
Staff	2.44	.98	1	5

Table 12

Correlations Between Mean Scores of Provider Responses to Questions 1-10 and Overall Satisfaction (Question 11)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
1. Q1	1.000	.095	.293**	.452**	.457**	.135	.327**	.252**	.385**	.314**	.399**
2. Q2	.095	1.000	.111	.051	.007	.129	-.196	-.028	-.042	-.055	-.049
3. Q3	.293**	.111	1.000	.467**	.284**	.298**	.259**	.287**	.288**	.330**	.261**
4. Q4	.452**	.051	.467**	1.000	.551**	.333**	.539**	.225*	.156	.349**	.433**
5. Q5	.457**	.007	.284**	.551**	1.000	.333**	.369**	.317**	.176	.363**	.513**
6. Q6	.135	.129	.298**	.333**	.333**	1.000	.228**	.107	.086	.372**	.245**
7. Q7	.327**	-.196*	.259**	.539**	.369**	.228*	1.000	.188*	.263**	.524**	.355**
8. Q8	.252**	-.028	.287**	.225**	.317**	.107	.188*	1.000	.487**	.327**	.585**
9. Q9	.385**	-.042	.288**	.156	.176	.086	.263**	.487**	1.000	.504**	.505**
10. Q10	.314**	-.055	.330**	.349**	.363**	.372**	.524**	.327**	.504**	1.000	.537**
11. Q11	.399**	-.049	.261**	.433**	.513**	.245**	.355**	.585**	.505**	.537**	1.000

Note. "**" indicates that the correlation is significant at the 0.01 level (2-tailed). "*" indicates that the correlation is significant at the 0.05 level (2-tailed).

Table 13

Stepwise Multiple Regression Analysis

Model	B	SE B	β	t	Sig.
1. (Constant)	1.032	.160		6.440	.000
Q8	.496	.064	.585	7.798	.000
2. (Constant)	.257	.202		1.269	.207
Q8	.389	.060	.458	6.442	.000
Q10	.515	.095	.387	5.439	.000
3. (Constant)	8.925E-02	.195		.457	.649
Q8	.337	.058	.397	5.769	.000
Q10	.409	.093	.307	4.380	.000
Q5	.246	.062	.275	3.942	.000
4. (Constant)	-3.231E-02	.200		-.162	.872
Q8	.280	.063	.330	4.454	.000
Q10	.313	.102	.325	3.076	.003
Q5	.261	.062	.292	4.226	.000
Q9	.187	.084	.175	2.210	.029

Table 14

Model Summary

Model	r	R^2	Std. Error of the Estimate
1.	.585	.342	.71
2.	.690	.476	.63
3.	.734	.538	.60
4.	.746	.557	.59

Table 15

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig
1. Regression	30.325	1	30.325	60.812	<.0001
Residual	58.344	117	.499		
Total	88.669	118			
2. Regression	42.179	2	21.090	52.622	<.0001
Residual	46.490	116	.401		
Total	88.669	118			
3. Regression	47.715	3	15.905	44.661	<.0001
Residual	40.955	115	.356		
Total	88.669	118			
4. Regression	49.397	4	12.349	35.847	<.0001
Residual	39.273	114	.344		
Total	88.669	118			

Table 16

Additional Survey Questions

	Number	Percentage (Rounded)
Desire Dedicated Review Station in Clinic		
Yes	103	87
No	4	3
No Opinion Marked	12	10
Desire reports/images displayed on personal computer		
Yes	109	92
No	8	7
No Opinion Marked	2	2

Table 17

Provider Comments

Emergency Room
1. My only complaint is that frequently old (archived) x-rays are not accessible in the system for comparison.

Cardiothoracic Surgery
1. System works very well, just need terminals at each clinic
2. Would like to see more PACS terminals, especially in general surgery/thoracic clinic.
3. Lack of viewbox in clinic is an enormous degradation in the quality of my practice.
4. Need to have the system in the CT clinic for accessibility.
5. Need terminals in the general surgery clinic where we see our patients.
6. Need PACS in the clinic. Currently must go two floors to review films.
7. Need more viewing stations at our surgery clinic.
8. Overall a good system, but needs wider implementation.
9. Limited input due to limited use of PACS.

Urology
1. I have used this system elsewhere, but not at WRAMC.
2. Not enough viewing stations.
3. All my "disagrees" related to the fact that there is no imager available in my area.

Pulmonary
1. Drawback is the inability to simultaneously view multiple films.
2. Too few reading stations; films not always on the system.
3. I have not used PACS.

Surgical Intensive Care Unit
1. There is a significant problem with retrieving old (archived) films; is great for new films - a large improvement.

Department of Medicine
1. Only problem is that images get archived too soon.
2. Reports would be great to have displayed for every image with voice writer. Speaker talks too fast to get all info quickly.
3. I would absolutely like to have reports and images displayed on my personal computer.

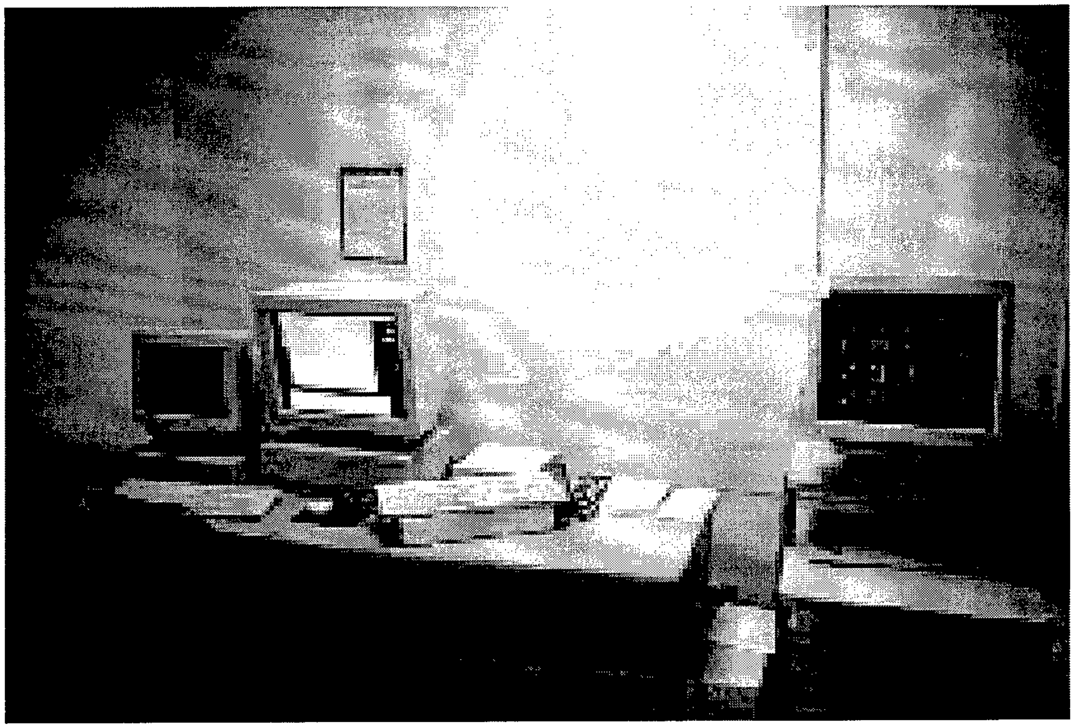

Figure 1. Patient Terminal (left) and Computer Radiology Acquisition Workstation (right).

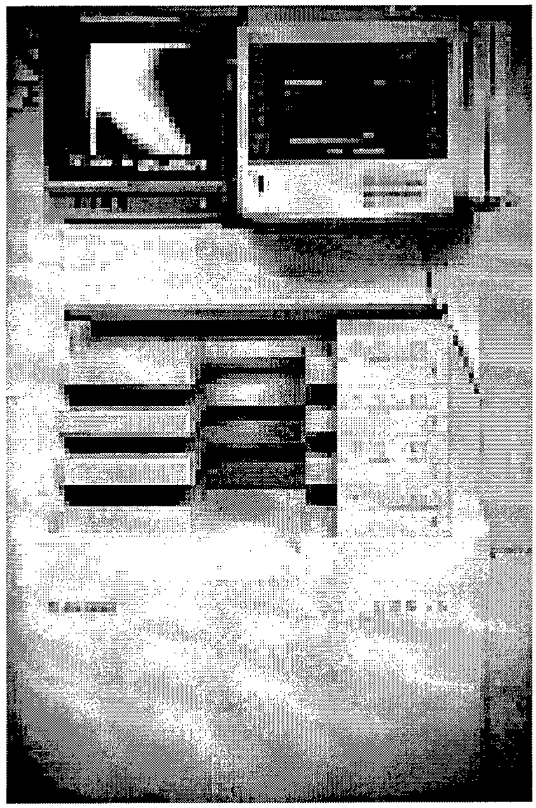

Figure 2. Fugi AC-3S Processor equipped with “stacker.”

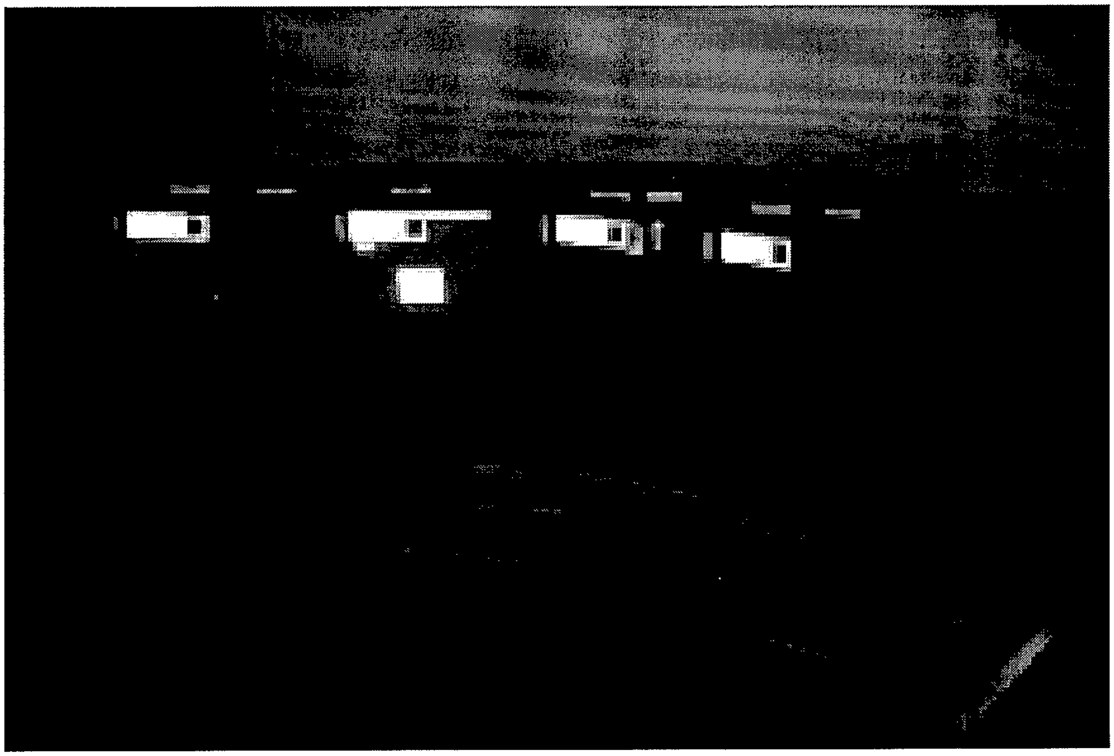

Figure 3. A “4A” Workstation for use by radiologists.

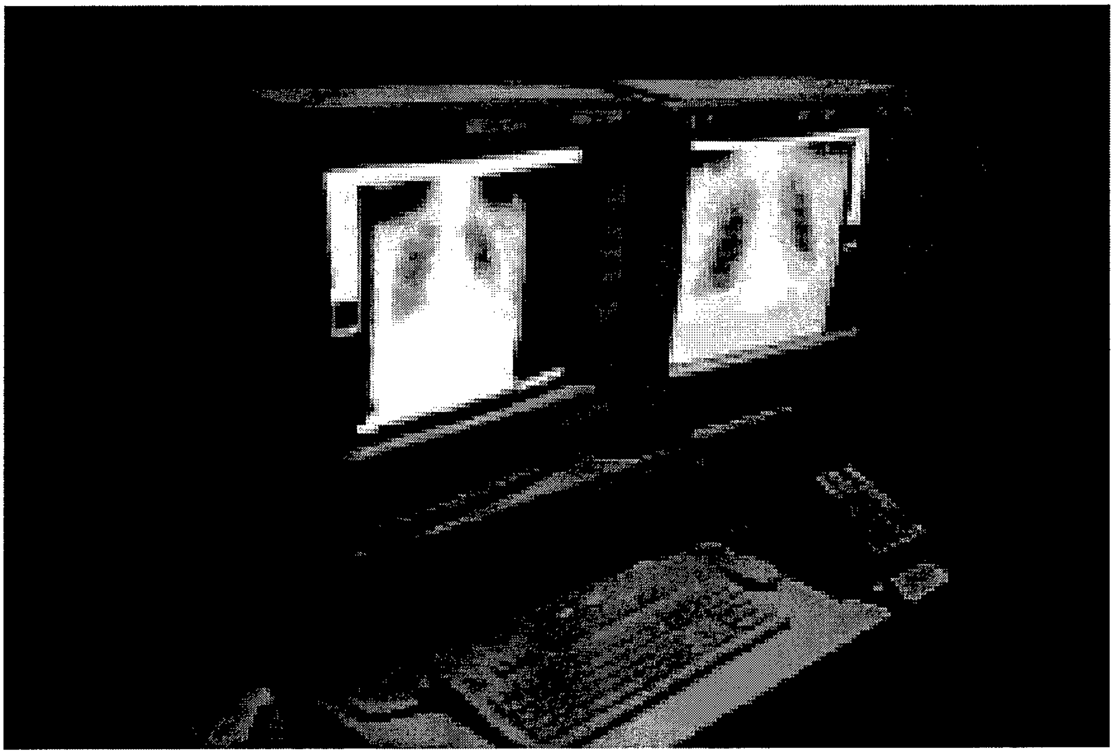

Figure 4. A “2C” Viewing Station

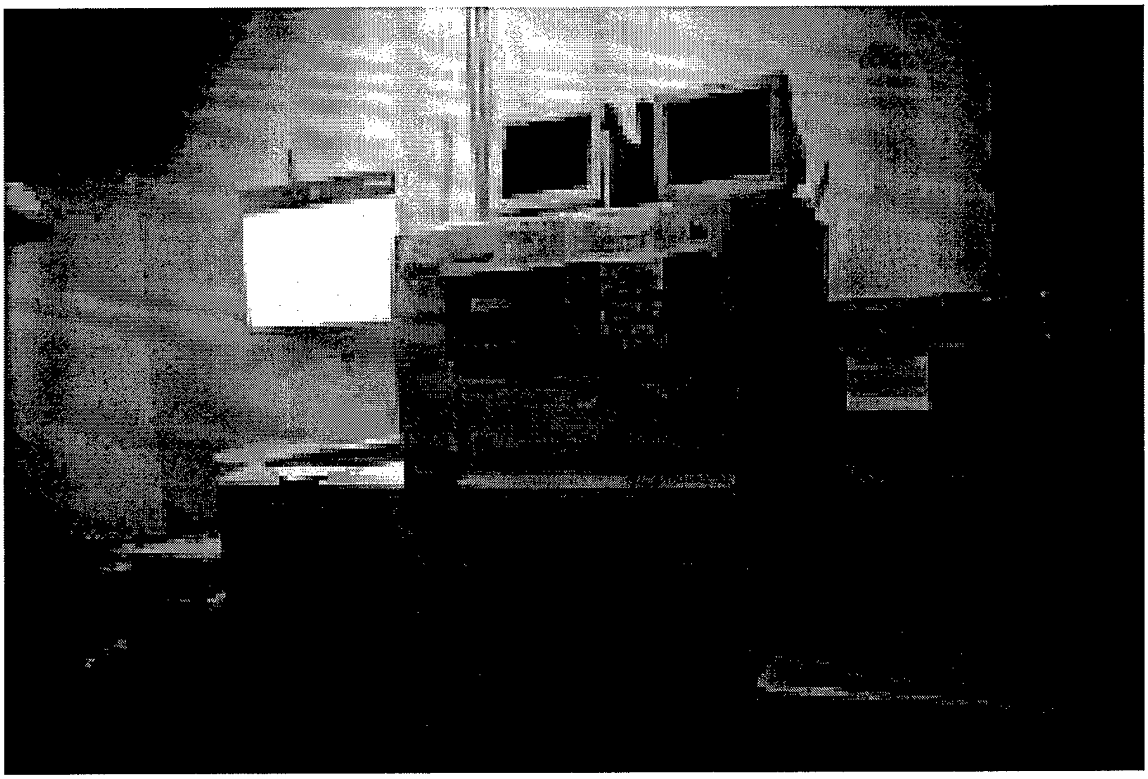

Figure 5. A Laser-Film Printer

Appendix A

Survey Instrument

PICTURE ARCHIVE AND COMMUNICATION SYSTEMS
(PACS)

In partial fulfillment of master's degree work, I am investigating the impact of the PACS on clinical practice at Walter Reed Army Medical Center (WRAMC). Would you please take a few moments to answer the following questions? Your ratings will provide valuable feedback. Although I ask for some background information, please be assured that the survey is anonymous and confidential. Thank you for your assistance.

Hunter R. Clouse, COL, DC

Please rate how much you agree or disagree with the following items on the scale provided. Circle the appropriate number corresponding with your response. For example, Strongly Agree =1, Agree Somewhat = 2, No Opinion/Neutral =3, Disagree = 4, Strongly Disagree = 5

	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
1. PACS provides rapid access to radiographic images.	1	2	3	4	5
2. PACS provides rapid access to the radiologist's formal report.	1	2	3	4	5
3. PACS results in fewer duplicated (repeated) radiographic examinations.	1	2	3	4	5
4. PACS improves the quality of care delivered.	1	2	3	4	5
5. PACS increases the efficiency of my clinical practice.	1	2	3	4	5
6. The ability to review images simultaneously in more than one location (i.e. the presence of multiple viewing stations) is important in my clinical practice.	1	2	3	4	5
7. The diagnostic accuracy (technical quality) of digital images is equal to or exceeds that of traditional film-based techniques.	1	2	3	4	5
8. I find the PACS at WRAMC to be "user friendly."	1	2	3	4	5
9. The PACS at WRAMC is reliable.	1	2	3	4	5
10. I am confident in my diagnoses using digital images.	1	2	3	4	5
11. Overall, I am satisfied with the performance of the PACS at WRAMC.	1	2	3	4	5

1. What is your position? Medical Student Intern Resident Attending Staff Other (Specify): ____________

2. What is your gender? Male Female

3. What is your status? Active Duty Contract Other (Specify): ________________

4. Would you like to have a dedicated review station located in your clinic? (Please check one) Yes _____ No _____

5. Would you like to see reports and images displayed on your personal computer? (Please check one) Yes _____ No _____

Appendix B

Instrument to Establish Content Validity

PICTURE ARCHIVE AND COMMUNICATION SYSTEMS
(PACS)

Please rate the relevance of each of the following to the listed objective. Circle the appropriate number corresponding with your response. For example, Not Relevant =1, Somewhat Relevant = 2, Quite Relevant =3, Very Relevant = 4.

	Not Relevant	Somewhat Relevant	Quite Relevant	Very Relevant
BENEFITS TO THE DIAGNOSTICIAN (RADIOLOGIST)				
1. PACS provides rapid access to radiographic images.	1	2	3	4
2. The diagnostic accuracy (technical quality) of digital images is equal to or exceeds that of traditional film-based techniques.	1	2	3	4
3. I am confident in my diagnoses using digital images.	1	2	3	4
BENEFITS TO THE REFERRING PHYSICIAN				
4. PACS increases the efficiency of my clinical practice.	1	2	3	4
5. The ability to review images simultaneously in more than one location (i.e. the presence of multiple viewing stations) is important in my clinical practice.	1	2	3	4
6. I find the PACS at WRAMC to be "user friendly."	1	2	3	4
7. The PACS at WRAMC is reliable.	1	2	3	4
8. Overall, I am satisfied with the performance of the PACS at WRAMC.	1	2	3	4
9. PACS provides rapid access to the radiologist's formal report.	1	2	3	4
BENEFITS TO THE PATIENT				
10. PACS results in fewer duplicated (repeated) radiographic examinations	1	2	3	4
11. PACS improves the quality of care delivered.	1	2	3	4

References

Andriessen, J.H.T.H., Ter Haar Romeny, B. M. Binkhuysen, F.B.H, Van der Horst-Bruinsma, I.E. (1989). Savings and costs of a picture archiving and communication system in the university hospital Utrecht. SPIE Medical Imaging: PACS System Design and Evaluation, 1093, 578-583.

Arenson, R. L., Chakraborty, D. P., & Seshadri, S. B. (1990). The digital imaging workstation. Radiology, 176, 303-315.

Becker, S. H., & Arenson, R. L. (1994). Costs and benefits of picture archiving and communication systems. Journal of the American Informatics Association, 1 (5), 361-371.

Cooper, D. R., & Emory, C. W. (1995). Business Research Methods. Chicago, IL: Irwin.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of test. Psychometrica, 16, 297-334.

Crowe, B. L. (1992). Overview of some methodological problems in assessment of PACS. Intetnational Journal of Bio-medical Computing, 30, 181-186.

Donobedian, A. (1982). The Criteria and Standards of Quality. Ann Arbor, MI: Health Administration Press.

Drummond, M. F., Stoddard, G. L., & Torrance, G. W. (1987). Methods for the Evaluation of Health Care Programs. Oxford, England: Oxford Medical Publications.

Dure-Smith, P., & Fymat, A. L. (1997). Teleradiology: will it transform the practice of radiology? Radiology, 203 (3), 49A-50A.

Evans, R. G. (1989). The economic impact of technology on diagnostic imaging at a university medical center. American Journal of Radiology, 153, 179-183.

Feldstein, P. J. (1994). Health Policy Issues. Ann Arbor, MI: AUPHA Press/Health Administration Press.

Gillespy, T., & Rowberg, A. H. (1994). Dual lookup table algorithm: an enhanced method of displaying 16-bit gray-scale images on 8-bit RGB graphics systems. Journal of Digital Imaging, 7, 13-17.

Goldberg, M. A. (1996). Teleradiology and telemedicine. Radiologic Clinics of North America, 34 (3), 647-665.

Hilsenrath, P. E., Smith, W. L., Berbaum, K. S. (1991). Analysis of the cost-effectiveness of PACS. American Journal of Radiology, 156, 177-180.

Huang, H. K. & Taira, R. K. (1992). Infrastructure design of PACS. American Journal of Roentgenology, 158, 743-749.

Huda, W., Honeyman, J. C., Frost, M. M., & Staab, E. V. (1996). A cost-analysis of computed radiography and picture archiving and communication systems in portable radiology. Journal of Digital Imaging, 9 (1), 39-44.

Hunt, W. & Weichert Commercial Realtors (1998). Pricing and Terms [On-line]. Available: http://silo.com/comreal/huntoff.htm

Hynes, D. M., Stevenson, G., & Nahmias, C. (1997). Towards filmless and distance radiology. The Lancet, 350, 657-660.

Jonsson, A., Hannesson, P., Herrlin K., Jonsson, K., Andersen, R. & Pettersson, H. (1995). Computed vs. film-screen magnification radiography of fingers in hyperparathyroidism. Acta Radiologica, 36, 290-294.

Kato, H. (1994). Photostimulable phosphor radiography design considerations. In J. A. Siebert, G. T. Barnes, & R.G. Gould (Eds.), Specification, Acceptance Testing and Quality Control of Diagnostic X-Ray Imaging Equipment (pp. 731-770). New York: AIP.

Kido, S., Ikezoe, J, Takeuchi, N. and Kondoh, H. (1994). Interpretation of subtle interstitial lung abnormalities: conventional versus film-digitized radiography. Radiology, 192 (1), 171-176.

Kimme-Smith, C., Aberle, D. R., Sayre, J. W. Hart, E. M. Greaves, S. M., Brown, K., Young, D. A. Deseran, M. D. Johnson, T., Johnson, S.L. (1995). Effects of reduced exposure on computed radiography: comparison of nodule detection accuracy with conventional and asymmetric screen-film radiographs of a chest phantom. American Journal of Radiology, 165, 269-273.

Langlotz, C.P., Even-Shoshan, O., Seshadri, S. S., Brickman, I., Kishore, S., Kundel, H. L., & Schwartz, J. S. (1995). A methodology for the economic assessment of picture archiving and communication systems. Journal of Digital Imaging, 8 (2), 95-102.

Leckie, R. G., Goeringer, F., Smith, D. V. (1993). Early evaluation of MDIS workstations at Madigan Army Medical Center. SPIE Proceedings of Medical Imaging, 1897, 336-349.

Letsch, S. W. (1993). National health care spending in 1991. Health Affairs, 12, 94-110.

Likert, R. A., (1932). A techniques for the measurement of attitudes. Archives of Psychology, 140, 1-55.

Meyer-Ebrech, D. (1994). Picture archiving and communication systems (PACS) for medical application. International Journal of Bio-Medical Computing, 35, 91-124.

Miyahara, J. (1987). Imaging plate. In Y. Tateno, T. Iinuma, & M. Takano (Eds.), Computed Radiography (pp. 7-15). Tokyo, Japan: Springer-Verlag.

Nissen-Meyer, S. A., Fink, U., Pleier, M., & Becker, C. (1996). The full-scale PACS archive: a prerequisite for the filmless hospital. Acta Radiologica, 37, 838-846.

Osteaux, M., Van den Broeck, R., Verhelle, F., & de Mey, J. (1996). Picture archiving and communication system (PACS): a progressive approach with small systems. European Journal of Radiology, 122 166-174.

Protopapas, Z, Siegel, E. L., Reiner, B. I., Pomerantz, S. M., Pickar, E. R., Wilson, M., & Hooper, F. J. (1996). Picture archiving and communication system trainging for physicians: lessons learned at the Baltimore VA medical center. Journal of Digital Imaging, 9 (3), 131-136.

Seely, G. W., Fisher, H. D., Stempski, M. O., Borgstrom, M., Bjelland, J., & Capp, M. P. (1987). Total digital radiology department: spatial resolution requirements, American Journal of Radiology, 148, 421-426.

Siegel, E., & Brown, A. (1994). Preliminary impacts of PACS technology on radiology department operations. Proceedings of the Annual Symposium of Computer Applications in Medical Care, 917-21.

Smith, D. V., Smith, S., Sauls, F. (1992). Design strategy and implementation of the medical diagnostic image support system at two large military medical centers. SPIE Proceedings of Medical Imaging, 1654, 148-157.

Smith, D. V., Smith, S., Bender, G. N., Carter, J. R., Kim, Y., Cawthon, M. A., Leckie, R.G., Weiser, J. C., Romlein, J., & Goeringer, F. (1995). Evaluation of the medical diagnostic imaging support system based on 2 years of clinical experience. Journal of Digital Imaging, 8 (2), 75-87.

Sonoda, M., Takano, M., Miyahara, J., & Kato, H. (1983). Computed radiography utilizing scanning laser stimulated luminescence. Radiology, 148, 833-838.

Stormer, J., Boole, S. R., Sund, T., Weller, G. E. R., & Gitlin, J. N. (1997). ROC - study of a teleradiology workstation versus film readings. Act Radiologica, 38, 176-180.

Straub, W. H. & Gur, D. (1990). The hidden costs of delayed access to diagnostic imaging information: impact on PACS implementation. American Journal of Radiology, 155, 613-616.

Strickland, N. H. (1996). Review article: some cost-benefit considerations for PACS: a radiological perspective. British Journal of Radiology, 69 (828), 1089-1098.

Tucker, D. M., Souto, M., & Barnes, G. T. (1993). Scatter in computed radiography. Radiology, 188, 271-274.

Tucker, D. M., Barnes, G.T., & Koehler, R. E. (1995a). Picture archiving_communication systems in the intensive care unit. Radiology, 196, 297-304.

Tucker, D. M., & McEachern, M. (1995b). Quality assurance and quality control of an intensive care unit picture archiving and communication system. Journal of Digital Imaging, 8 (2), 95-102.

Van Gennip, E. M. S. J., & Gremy, F. (1993). Challenges and opportunities for technology assessment in medical informatics. Report of a MEDINFO '92 workshop. Medical Informatics, 18 (3), 179-184.

Van Gennip, E. M. S. J., & Bakker, A. R. (1993). Challenges and opportunities for technology assessment in medical informatics. Case study: PACS. Medical Informatics, 18 (3), 209-218.

Van Gennip, E. M. S. J., Bakker, A. R. & Greberman, M. (1992). Do the benefits outweigh the costs of PACS? The results of an international workshop on technology assessment of PACS. Computer Methods Programs Biomedical, 37, 265-271.

Waltz, C. F., Strickland, O. L., & Lenz, E. R. (1984). Measurement in Nursing Research. Philadelphia, PA: F. A. Davis Company.

Warburton, R. N., Fisher, P.D., Nosil, J. (1990). Digital diagnostic imaging with a comprehensive PACS: hypothetical economic evaluation at a large community hospital. Journal of Digital Imaging, 3, 101-107.

Warner, K. E., & Luce, B. R. (1982). Cost-benefit and cost-effectiveness analysis in health care: principles, practice and potential. Ann Arbor, MI: Health Administration Press.

Wells, P. N. T., Garrett, J. A., & Jackson, P. C. (1991). Assessment criteria for diagnostic imaging technologies. Medical Progress Through Technology, 17, 93-101.

Williams, S. J. & Torrens, P. R. (1993). Introduction to health services. Albany, NY: Delmar.